ACS6132 Agent-based modelling and multi-agent systems

Module leader: Robin Purshouse, r.purshouse@sheffield.ac.uk

Assessment 2023/24: MEng and MSc programmes
Release date: 25 September 2023

1. Overview

ACS6132 is a 15 credit module that comprises 100% continuous assessment. You will be working as a member of a small team, using a systems engineering approach to develop a novel agent-based simulation. You will begin by running an existing benchmark model. You will then developing your own proposal for a new feature for the model, using learning from the taught content of the module together with wider reading. In your groups, you will design and implement an enhanced version of the model that integrates prioritised features proposed by your team members. Finally, you will run sensitivity analyses for the model to show how changes to model parameters affect the model output.

2. Background to the benchmark simulation–the Artificial Anasazi

The *Artificial Anasazi* model is widely recognised as a milestone application of agent-based modelling. This model attempts to recreate half a millennium of spatial population dynamics in Long House Valley, Arizona, which was inhabited by Anasazi ("Ancient Ones") peoples between 1800 B.C. and 1300 A.D. Long House Valley is notable archaeologically for the detailed replication of its climate and settlements between 200 and 1500 A.D. A portion of this data was used by Robert Axtell and colleagues to develop an agent-based model (ABM) of Anasazi society that aimed to represent the temporal and spatial dynamics of the population in the valley. The model was initially developed in the now-defunct *ascape* ABM software, but has been reproduced and enhanced on some contemporary platforms, including *MASON* and *NetLogo*. No published implementation yet exists for the *Repast HPC* platform. Instead, you will be working with a Repast HPC version of the model that was made specifically for the module.

A basic description of the model is given below. Note that this description does not contain all the intricacies of the simulation. For these, you should refer in the first instance to Marco Janssen's 2009 analysis of the model, *Understanding Artificial Anasazi*: http://jasss.soc.surrey.ac.uk/12/4/13.html

2.1 Entities in the model

Each agent in the Artificial Anasazi model represents a *household*, which is the smallest population unit available in the archaeological data. Each household has a current age (in years), a preordained 'death age' (also in years), a further preordained age at which the household will become infertile, and a stock of maize (in kg, with a maximum of 1600 kg). The household is also associated with two locations on a network: (1) the location of the household's residence; (2) the location of the household's field of maize.

Agents are removed from the simulation when they reach their death age. Agents are also removed from the simulation if they do not have sufficient maize to feed the household that year (800 kg). Agents also 'fission' new agents with a defined annual probability for years when the existing agents are of fertile age (16 to the maximum fertile age).

2.2 Agent network

The agent network is represented by a Cartesian grid of cells, each representing an area measuring 100 metres by 100 metres, that depicts Long House Valley. Agents' residences and fields occupy locations on the network. Agents may share locations for their residences with other agents, but only one field per network cell is permitted. Environmental conditions on the network vary according to historical climatic data and are used to: (1) generate annual maize yields for fields based on a normal distribution; (2) define which cells are sources of water. Stocks of maize in agent residences on the network are also reduced each year to account for losses.

Agents do not communicate directly across the network. Rather, the local distributions of past-year maize yields within the network are used by agents to estimate yields for the coming year for their own existing field and unoccupied cells on the network. Agents may decide to move either of their locations on the network based on this information.

2.3 Agent decision-making

In the model, agents make decisions on where to site their residence and field locations on the network. The decision-making follows a simple rule-based system:

1. The agent calculates the expected maize production for its field in the coming year, and compares this with its existing stock and needs.
2. If the agent judges that it will have insufficient maize, it moves its locations on the network.
3. The agent chooses a new location for its field based on the following conditions:
    a. the new location must not be an existing field or residence;
    b. the expected annual maize production at the new location must be at least 800 kg;
    c. if multiple cells meet conditions (a) and (b) then the cell closest to the agent's current residence is selected;
    d. if no cell meets these conditions then the agent leaves the valley.
4. The agent then chooses a new location for its residence based on the following conditions:
    a. the residence must be within 1 km of the field;
    b. the location must not be a field;
    c. the location must not have a greater potential yield than the field;
    d. if multiple cells satisfy these conditions then the cell closest to a water cell is selected;
    e. if no cells satisfy these conditions then condition (c) is relaxed first, followed by condition (a).

2.4 Model inputs and initialisation

Each cell in the network is associated with a zone (General Valley Floor, North Valley Floor, Midvalley Floor, Arable Uplands, Uplands Nonarable, Kinbiko Canyon or Dunes). For each zone, for each year, the climatic conditions (as measured by the Palmer Drought Severity Index) are provided as an input and can be mapped to a measure of maize yield. For each cell, for each year, a further input identifies whether that cell contains a water source.

The simulation is initialised with 14 agents in the year 800 A.D. and is simulated forward to 1350 A.D. using a discrete time step of 1 year.

2.5 Simulation results

Axtell and colleagues searched over the parameter space of the model to identify a best fit to the observed number of households in the valley over time (which is itself an estimate based on the archaeological evidence). The goodness of fit was calculated using an integral of absolute error metric based on the difference between annual model outputs and the observed data. The results are reproduced in Figure 1 below.

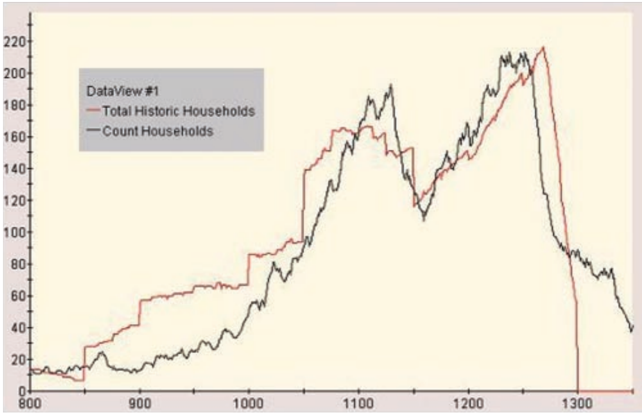

Figure 1: Observed (red) versus simulated (blue) population dynamics in Long House Valley. The horizontal axis is the year; the vertical axis is the number of households / agents. Reproduced from Axtell et al.'s *Population growth and collapse in a multiagent model of the Kayenta Anasazi in Long House Valley*, 2002.

Whilst the simulation captures the general trend in the growth and decay of the Anasazi population, it tends to understate the population during the period 900 A.D. to 1000 A.D. and also does not capture the full extent of the rapid depopulation of the valley in the late 13th century.

The model suggests that simple decision-making based on relatively crude forecasts of the harvest is sufficient to reproduce population trends in the Anasazi in Long House Valley. However, the inability of any model parameterisations to reproduce the final collapse in population within the valley suggests that additional mechanisms are needed to fully explain the archaeological history of the Anasazi. As part of the module, you will aim to identify alternative agent decision-making and interaction mechanisms that might better reproduce the population trends.

3. Software implementation requirements

The *REcursive Porous Agent Simulation Toolkit (Repast)* was initially developed by the University of Chicago and Argonne National Laboratory during the early 2000s, building on concepts from the earlier ABM toolkit *Swarm* developed by the Santa Fe Institute. Repast is maintained software with a large user base. It presently exists in three versions: (1) *Repast Simphony*, which is a Java-based system with a graphical user interface, designed for use on workstations; (2) *Repast for High Performance Computing (HPC)*, which is a collection of C++ libraries for use in multi-core environments; and (3) *Repast4Py*, which is a Python implementation of Repast HPC. More information about Repast can be found at: https://repast.github.io

In your week 1 and week 2 laboratories you will have the opportunity to work through a tutorial that will introduce you to Repast HPC.

For the assessment, you will have access to an existing model written in C++ that exploits the Repast HPC libraries and you are **required** to implement your enhancements to the model also in C++. However, your group is free to choose its own preferred software to implement model analysis workflows (e.g. using Matlab, R or Python).

4. Components of assessment

ACS6132 has six intended learning outcomes (ILOs):

- ILO1. Explain how key themes in complex adaptive systems (such as emergence and adaptation) can be represented using agent-based approaches.
- ILO2. Describe and evaluate the decision-making and network architectures available for agent-based simulations and multi-agent systems.
- ILO3. Design small-scale multi-agent systems using UML methods.
- ILO4. Implement a multi-agent simulation using open-source software tools.
- ILO5. Analyse a multi-agent simulation using design of experiments methods.
- ILO6. Apply agile project management processes to a collaborative software development project.

Assessment of the ILOs is composed of five integrated components, with later components worth more marks than earlier components. You will receive rapid feedback for the earlier components to enable you to learn and respond in time to the demands of the later components. A summary of the components is given in Table 1. Further details about each component are provided in separate briefings below.

Table 1: Overview of module assessment

Component (% module mark)	**Due date**	**Description**
1. Understand the model (5% group)	Weds Week 5 (9am, 25 October)	Live demo of running the existing Artificial Anasazi model (10 minutes + 10 minutes Q&A + feedback)
2. New feature modelling (15% individual)	Weds Week 7 (9am, 8 November)	Presentation of the proposed new modelling feature concept and equations (5 minutes + 5 minutes Q&A + feedback per team member)
3. Group model design (20% group)	Weds Week 9 (9am, 22 November)	Presentation of the proposed integrated group modelling concept, equations and UML (10 minutes + 10 minutes Q&A + feedback)
4. Group model demonstration (25% group)	Weds Week 12 (9am, 13 December)	Live demo of running the new model and exploring the impact of new model parameters (15 minutes + 5 minutes Q&A + feedback)
5. Final report and project management (35% group)	Mon Exam Week 1 (12 noon, 16 January)	Written report (no maximum limit, but guidelines of 8 pages). This guidance excludes the title page, executive summary, contents page, and references. See Table 6 for further details). Project management is assessed **weekly** from week 3 to week 12 (1% per week for use of agile project management)

For the purposes of final individual assessment, please note that all group marks are converted to individual marks via moderated peer assessment. See Section 5 for further details.

4.1 Component 1: Understand the model

The purpose of this component is to ensure that you have engaged with the existing Artificial Anasazi model, in terms of concept, equations and implementation. In Week 5, you will give a short overview of the model and demonstrate how it can be run and analysed in an empirical setting. The live demo should demonstrate the software running in real-time. You will be required to submit via Google Drive a compressed file of the materials used in the demo.

Marking Criteria

Component 1 is worth 5% of the overall module mark. Your team will be scored according to the following criteria:

Table 2: Marking criteria for Component 1

Marking criterion [intended learning outcome]	**Scoring (module marks)**
Explanation of the model [ILO1,2]	2% - Clear overview of the modelling concept and equations/rules 1% - Minor issues with the coherence or correctness of the overview 0% - Major issues with the coherence or correctness of the overview
Live demonstration of the model [ILO1,5]	3% - Demonstration of the model running in real-time, showing how its emergent output is affected by choice of model parameters – covering at least two of the parameters in Table 4 of Janssen (2009) 2% - Demonstration of the model running in real-time, with limited analysis of how its output is affected by model parameters 1% - Demonstration of the model running in real-time 0% - Unable to run the model

4.2 Component 2: New feature modelling

Each team member is **individually** required to contribute a proposed feature for an enhanced Artificial Anasazi model and pitch this to their team members for consideration. The feature may relate to agent decision-making and/or agent networks–and should be based on lecture materials, with further inclusion of wider reading as appropriate. A presentation pitch of the proposal will be communicated formally to team members and module assessors in Week 7. The proposal should explain the concept for the feature and must include a formal specification of the revised or extended model structure as equations or rules. It is important to explain how your proposed feature relates to the original model. You should create the presentation in appropriate software, e.g. Powerpoint or Beamer. You will also be required to submit a copy of the presentation via Blackboard.

Marking Criteria
Component 2 is worth 15% of the overall module mark. You will be scored **individually** according to the following criteria:

Table 3: Marking criteria for Component 2

Marking criterion [intended learning outcome]	**Scoring (module marks)**
Concept overview [ILO1,2]	5-6% - Clearly motivated and coherent proposal for a new feature relating to agent decision-making and/or network, with reference to lecture materials and (if appropriate) wider reading 3-4% - Clearly motivated proposal, but moderate re-work would be needed to ensure that the new concept is intellectually coherent 1-2% - Major revision would be needed to deliver a justifiable and coherent model enhancement 0% - No clear proposal for a model feature
Model structure [ILO2]	5-6% - Accurate equations and/or rules that describe the model structure for the feature using consistent and clearly explained notation 3-4% - Some good use of equations and/or rules, but occasional lapses in the consistency or clarity of the notation 1-2% - Attempted use of equations and/or rules to describe the model structure, but with major issues to correctness or clarity 0% - No clear description of the model structure for the proposed feature
Presentation quality [ILO1,2]	3% - Engaging presentation that makes effective use of the available 5 minutes 1-2% - some issues with the quality or timing of the presentation 0% - incoherent, low quality, or badly mistimed presentation

4.3 Component 3: Group model design
Once your team members have pitched their proposed features, it is time to take the ideas and integrate them into an enhanced design for the Artificial Anasazi model. Since some of the ideas may conflict with each other or not be feasible to implement within a short time frame, there is no requirement to integrate all group member's suggestions. However, it is expected that at least two concepts will be included in the new proposal (unless there are reasonable circumstances that would prevent this). It is likely that some of the details will need to be revised in order to ensure a coherent integration of concepts. You will also need to include UML diagrams showing how the software design will be realised. You will formally present your group's proposal for the new model enhancement in Week 9. You will also be required to submit a copy of the presentation via Blackboard.

Marking Criteria
Component 3 is worth 20% of the overall module mark. Your team will be scored according to the following criteria:

Table 4: Marking criteria for Component 3

Marking criterion [intended learning outcome]	**Scoring (module marks)**
Feature prioritisation [ILO6]	3% - Coherent prioritisation of team member features, assessed against a set of criteria (e.g. completeness of proposal, feasibility of implementation, compatibility with other features). 2% - Some attempt to prioritise team member features against a set of criteria 0-1% - No clear prioritisation scheme adopted
Concept overview [ILO1,2]	4-5% - Clearly motivated and coherent proposal for an integrated enhancement to the existing agent decision-making and/or network, with reference to the original pitches and incorporating new ideas as appropriate. 3% - Clearly motivated proposal, but moderate re-work needed to ensure that the new concept is intellectually coherent 2% - Major revision needed to deliver a justifiable and coherent model enhancement 0-1% - No clear proposal for model development
Model structure [ILO2]	4-5% - Accurate equations and/or rules that describe the enhanced model structure using consistent and clearly explained notation 3% - Some good use of equations and/or rules, but occasional lapses in the consistency or clarity of the notation 2% - Attempted use of equations and/or rules to describe the model structure, but with major issues to correctness or clarity 0-1% - No clear description of the model structure
UML design [ILO3]	4-5% - Good quality UML diagrams, with no errors 3% - Minor issues present in the UML diagrams 2% - An attempt at using UML, but with substantial issues with its accuracy 0-1% - No UML diagrams presented
Presentation quality [ILO1,2,3]	2% - Engaging presentation that makes good use of the available 10 minutes 1% - Some issues with the quality or timing of the presentation 0% - Incoherent, low quality, or badly mistimed presentation

4.4 Component 4: Group model demonstration
Once you have finalised the integrated model design, taking account of feedback from the module assessors, you will next move on to implementation of the new model in C++. Using an agile project management process to distribute work amongst your team members over several sprints, you will develop, verify, and analyse the model.

You will then, as a team, give a live demo of your model analysis workflow in Week 12. You will be required to submit via Google Drive a compressed file of the materials used in the demo.

Marking Criteria
Component 4 is worth 25% of the overall module mark. Your team will be scored according to the following criteria:

Table 5: Marking criteria for Component 4

Marking criterion	**Scoring (module marks)**
Model implementation	7-10% - Complete or mostly complete implementation of the integrated model design, showing the model running in real-time in the live demo. 6% - Partially complete implementation of the integrated model design, where the model is able to execute as part of the live demo. 4-5% - Partially complete implementation of the integrated model design, where there are issues with executing the model as part of the live demo. 0-3% - Substantial issues with the model implementation. Substantial additional coding or debugging needed.
Model verification	4-5% - Verification tests designed, implemented and executed successfully as part of the live demo, where the tests satisfactorily cover the functional behaviour of the new features. 2-3% - Verification tests designed, with at least one implemented and able to test some of the functional behaviours anticipated by the new features. 0-1% - Verification tests not designed, or designed but not implemented.
Model analysis	6-8% Sampling plan for key model parameters designed, executed and analysed. Clear presentation of the impact of the new features, identifying the relationships between the model parameters and the emergent model output. 5% Sampling plan for key model parameters designed and executed, but with limited analysis of the results. 4% Sampling plan for key model parameters designed but not fully executed, with limited analysis of any available results. 0-3% Sampling plan not designed, or designed but without any execution. No model analysis attempted.
Presentation + live demo quality	2% - Engaging presentation and demo that makes good use of the available 15 minutes 1% - Some issues with the quality or timing of the presentation 0% - Incoherent, low quality, or badly mistimed presentation

4.5 Component 5: Final report and project management

The final report is a technical document that describes and critically appraises the work undertaken by your team. In addition to the development and analysis of agent-based models, it allows your team the opportunity to demonstrate your learning from module lectures and wider reading.

Table 6: Guidance on final report structure and marking criteria

Section	**Page guidelines**	**Module marks available**	**Expected contents [intended learning outcome]**
Executive summary	1 page	3%	Clear overview of the report, with a focus on purpose and findings. [ILO1-6]
1. Background and purpose	2 pages	5%	Critical appraisal of how agent-based models and multi-agent systems can provide representations of complex adaptive systems. Assesses the strengths and limitations of the original Artificial Anasazi model as an adequate representation of the mechanisms of population dynamics of an ancestral Puebloan society. [ILO1,2]
2. Final group model design	2 pages	5%	Details the final concept, equations and/or rules, and UML design for the group's enhancement to the original model. [ILO1,2,3]
3. Model analysis	2 pages	5%	Clear overview of the model analysis workflow and the final results. Critically appraises the strengths and limitations of the enhanced model in relation to the original. [ILO1,2,5]
4. Reflection	2 pages	5%	Critical appraisal of the project process and outcomes, including the strengths and limitations of the agile approach used. Within the context of the team as a whole, describes the capabilities of the team and how activities were allocated during sprints. [ILO6]
References	2 pages	2%	Accurate referencing of sources used in the report, using a consistent format. [ILO1-6]

The structure and required contents of the technical report are shown in Table 6 above. The final report must be submitted electronically via the Turnitin submission link on the ACS6132 Blackboard site. A compressed file containing all the materials used to produce the final model and analysis must be submitted via Google Drive. The deadline for submission is **12 noon 16 January 2024**. There is no maximum page limit for the report, but it is not expected that groups will stray far from the guidance given in Table 6. Font size 11 should be used for the report, with 2.5cm margins all round.

10% of the group module marks in the final component relate to the agile development process. More details are provided in Section 5 below.

5. Group working

In ACS6132, 85% of the assessment is based on collaborative working within a small team of students. Your fellow team members might include undergraduate finalists on ACSE's MEng programmes, postgraduates on ACSE's MSc programmes, undergraduates from other departments who have elected to take the module as part of their studies, and research students who are taking the module as part of their doctoral development programme. Your team will have a diverse range of skills and experiences–and you will need to make the most of these, whilst navigating the time constraints on the availability of the Linux machines in the Sir Henry Stephenson Building Room 2020 laboratory.

You will use agile methods to manage the project–specifically the *Scrum* approach. You will learn about Scrum in some of the early lectures and put this in to practice as part of your team's day-to-day engagement with the module. You will be working with the implementation of Scrum used in Atlassian's *Jira* software, which is an industry standard tool for agile project management (https://www.atlassian.com/software/jira). You will also implement source code control using Atlassian's *Bitbucket* software (https://www.atlassian.com/software/bitbucket).

The ability of your group to operate to agile project management principles will be scrutinised by the module assessors on a weekly basis between Week 3 and Week 12 inclusive. Each week, your team will be scored against the following assessment criteria:

Table 7: Marking criteria for Component 5 project management

Marking criterion [intended learning outcome]	**Scoring (module marks per week – 10% in total)**
Project management [ILO6]	1% - Agile process fully operational, with Jira board and Bitbucket repositories refreshed. Team members clearly allocated to roles and aware of sprint goals. 0.5% - Minor issues with the operation of the agile process, in terms of tool use, role allocation, or sprint goals. 0% - Either no use or superficial use of agile project management processes.

At three points during the semester, you will be asking to participate in **self and peer assessment**. The results of the self and peer assessment are used to detect and diagnose any problems within groups and to moderate individual marks based on the group total. The formula used is:

> Individual mark = Individual component + Group mark * Individual average peer score / Group average peer score.

Scores are generated by answers to the following questions:

Please rate each group member's overall contribution to meetings:
Score 1: Regularly does not attend, arrives late and/or contributes little or nothing to discussions.
Score 2: Attends some meetings and/or contributes little to the discussion.
Score 3: Attends some meetings but contributes well to discussions when present or attends all meetings but contributes little.
Score 4: Attends most/all meetings and contributes to discussions and ideas.
Score 5: Attends all meetings, actively contributes with ideas and to discussions and actively encourages other members of the group to contribute.

Please rate each group member's technical contribution to the project:
Score 1: Has made little technical contribution and/or work is technically weak.
Score 2: Has made some contribution, requires lots of support and encouragement from the group to undertake work and/or work is sometimes technically weak.
Score 3: Reasonable contribution, technically solid and gets on with their work as requested.
Score 4: Good contribution to the project, technically solid and demonstrates good initiative.
Score 5: Excellent contribution to the project that is technically very good, demonstrating excellent insight and initiative.

Please rate each group member's contribution to the project management and systems engineering:
Score 1: Poor project management and little or no systems engineering approach applied.
Score 2: Has made some contribution to project management and systems engineering, but requires lots of support and encouragement from the group to do this.
Score 3: Reasonable contribution, makes use of the available agile project management, source code control, and collaboration tools but could be more effective in their use.
Score 4: Good contribution to the project management including updating documents regularly as project progresses. Good use and understanding of appropriate systems engineering tools.
Score 5: Excellent project management and use of systems engineering tools including making regular updates to documents.

Please rate each group member's overall professionalism and group working skills:
Score 1: Does not engage well with the group, acts unprofessionally and is not supporting the group in the project.
Score 2: Engages most of the time but could do more to contribute to the group.
Score 3: Solid group member, professional and respects and supports other group members.
Score 4: Very good group member, professional, supports other group members and contributes more than others on average.
Score 5: An excellent team player and communicator, actively encourages and supports other group members and contributes well beyond expectations.

As part of the self and peer assessment, you are also **required** to respond to the following two open questions (1000 characters limit per answer):

1. What are your reflections so far on your own performance and your group's performance?
2. What are your reflections so far on the effectiveness of the communication methods being used by your group?

Please note that if you do not satisfactorily engage with the self and peer assessment process (e.g. by not performing an evaluation when invited to do so) then you may receive a marking penalty of **up to 10%** of the module marks.

6. General guidelines

Please pay attention to the following general guidelines for coursework assessment in ACSE.

6.1 Penalties for late submission

Late submissions will incur the usual penalties of a 5% reduction in the mark for every working day (or part thereof) that the component is late and a mark of zero for submission more than 5 working days late. For more information see: https://www.sheffield.ac.uk/ssid/exams

6.2 Feedback

Verbal and written feedback will be provided immediately after the submission of components 1, 2, 3 and 4. Feedback for the final report (component 5) will be provided within 10 working days, in line with ACSE expectations.

6.3 Unfair means

The individual component of assessment (Component 2) must be wholly your own work. For all other aspects of assessment you may collaborate with others within your own group; however you must not use work from other groups (plagiarism) or work together with other groups (collusion). Any suspicion of the use of unfair means will be investigated and may lead to penalties. For more information see: http://www.shef.ac.uk/ssid/exams/plagiarism

6.4 Extenuating circumstances

If you have any medical or special circumstances that you believe may affect your performance during the module then you should raise these with the Module Leader at the earliest opportunity. You will also need to submit an extenuating circumstances form. For more information see: http://www.shef.ac.uk/ssid/forms/circs